The physical nature of Sporadic-E

…what we know and how we know

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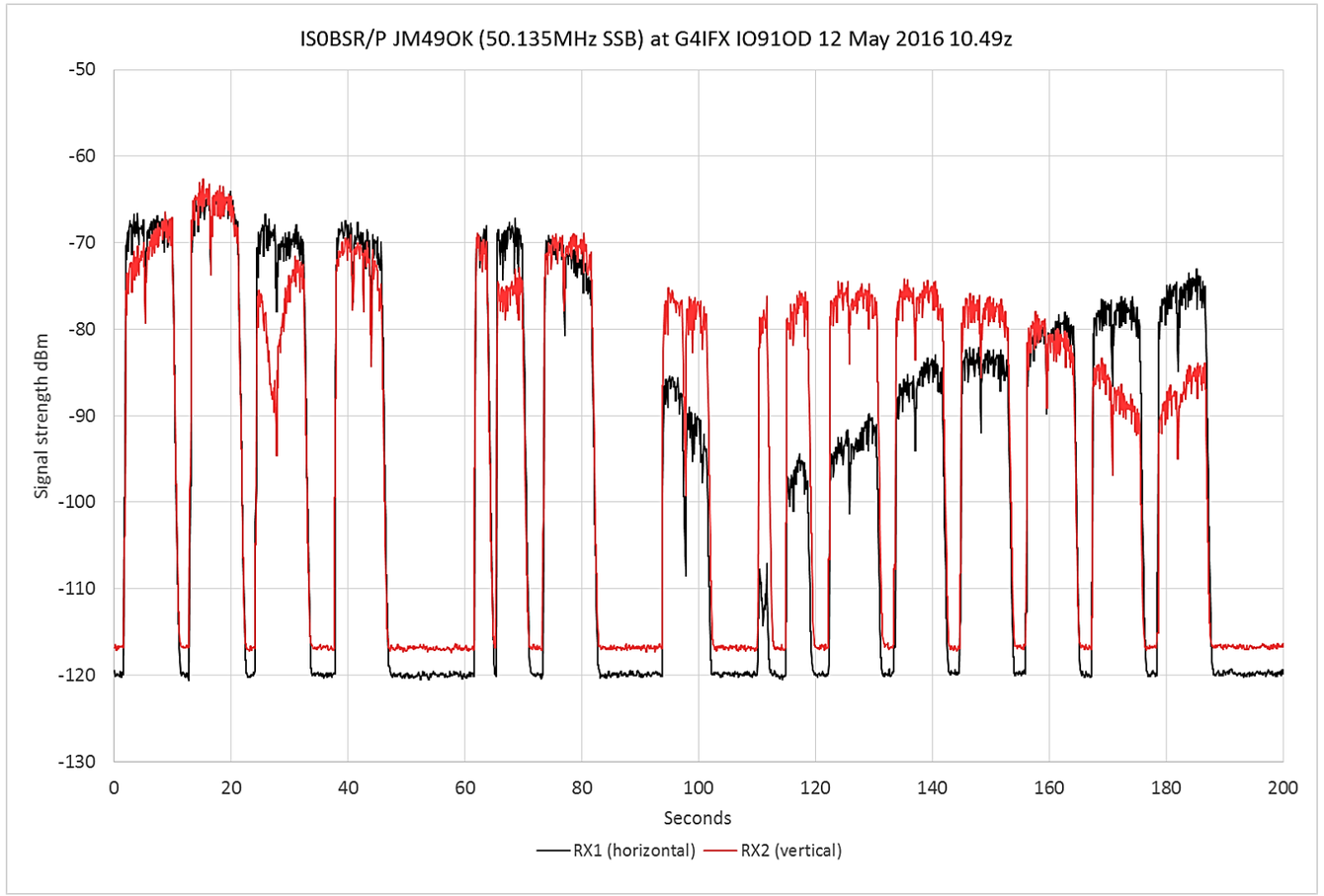
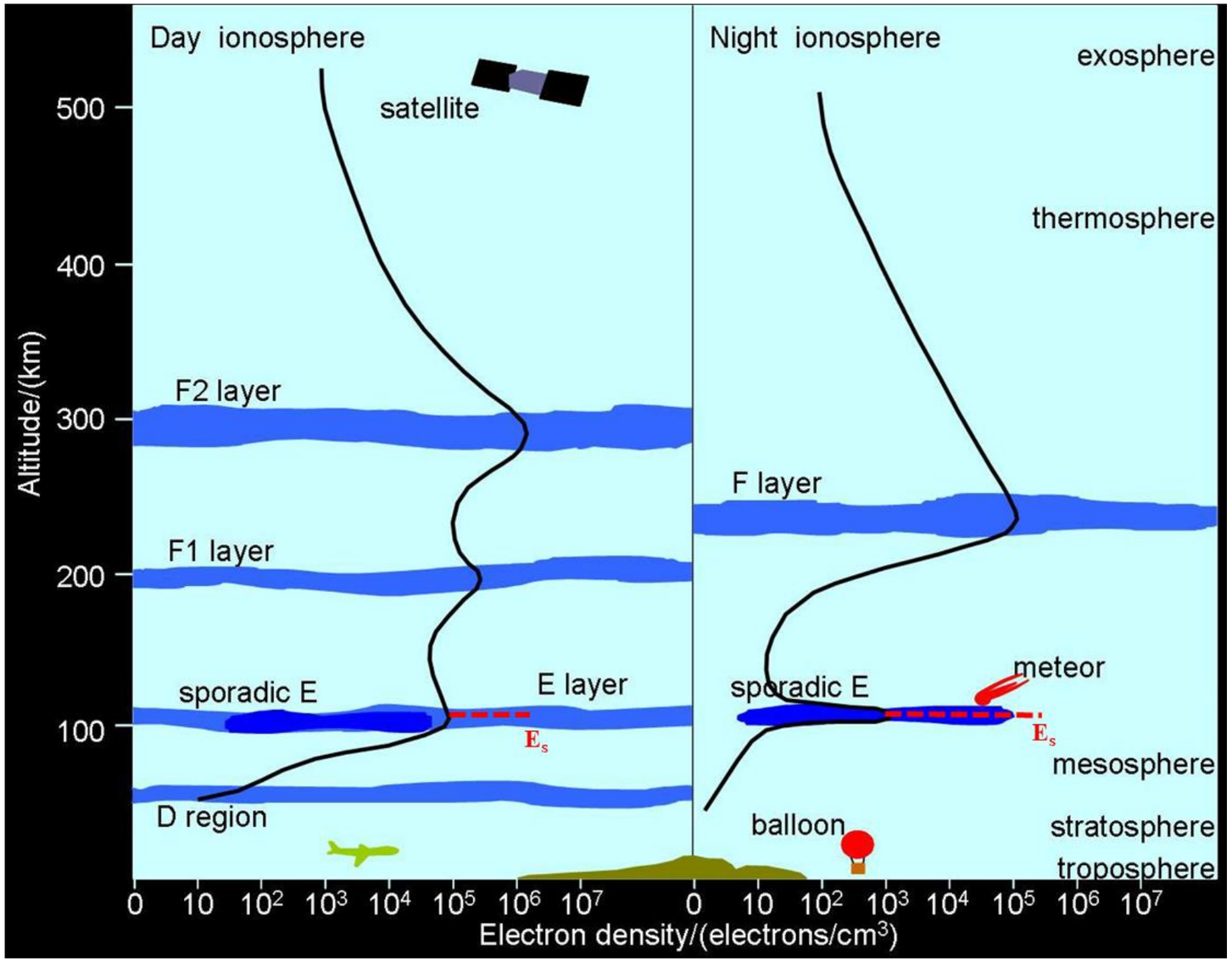
Es from the amateur radio perspective

- HF and VHF, to beyond 144 MHz
- Single-hop range up to 2500 km or so
- Appears from nowhere and can disappear just as quickly
- Intermittent, very difficult to predict
- Independent (almost) of the solar cycle
- Signals can be very strong
- Rapid fading
- Often very localised



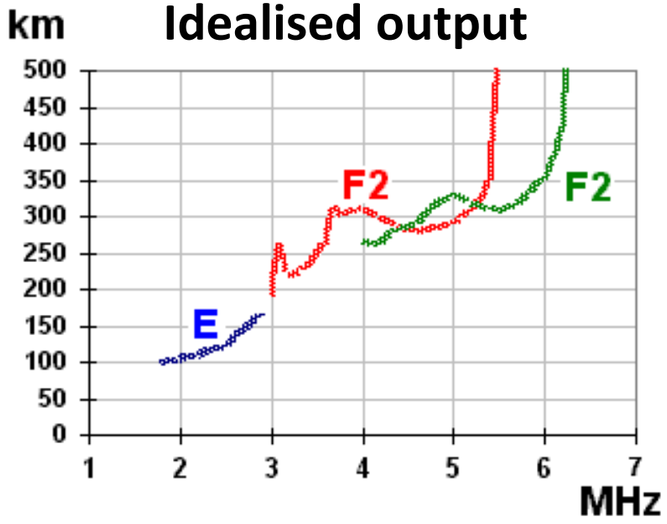
Es in the ionosphere



- The ‘background’ ionosphere is driven by solar activity
- The ‘background’ ionosphere can only reflect 50 MHz signals near sunspot maximum
- Sporadic-E is different, it happens across the solar cycle
- Es can be very ‘patchy’

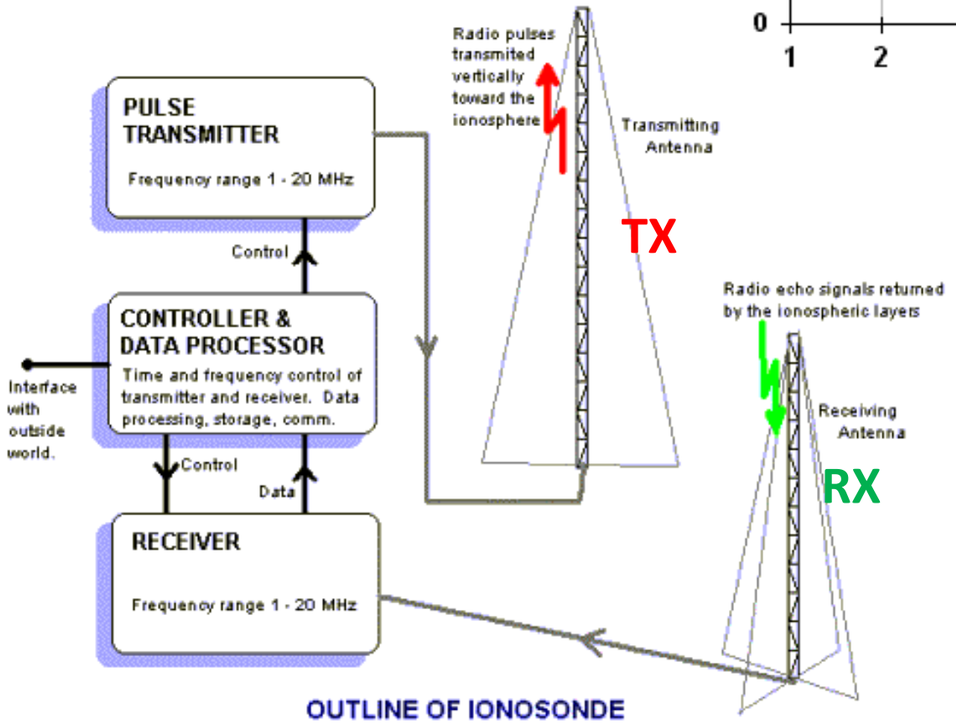
Investigating Es - Ionosondes

Idealised output

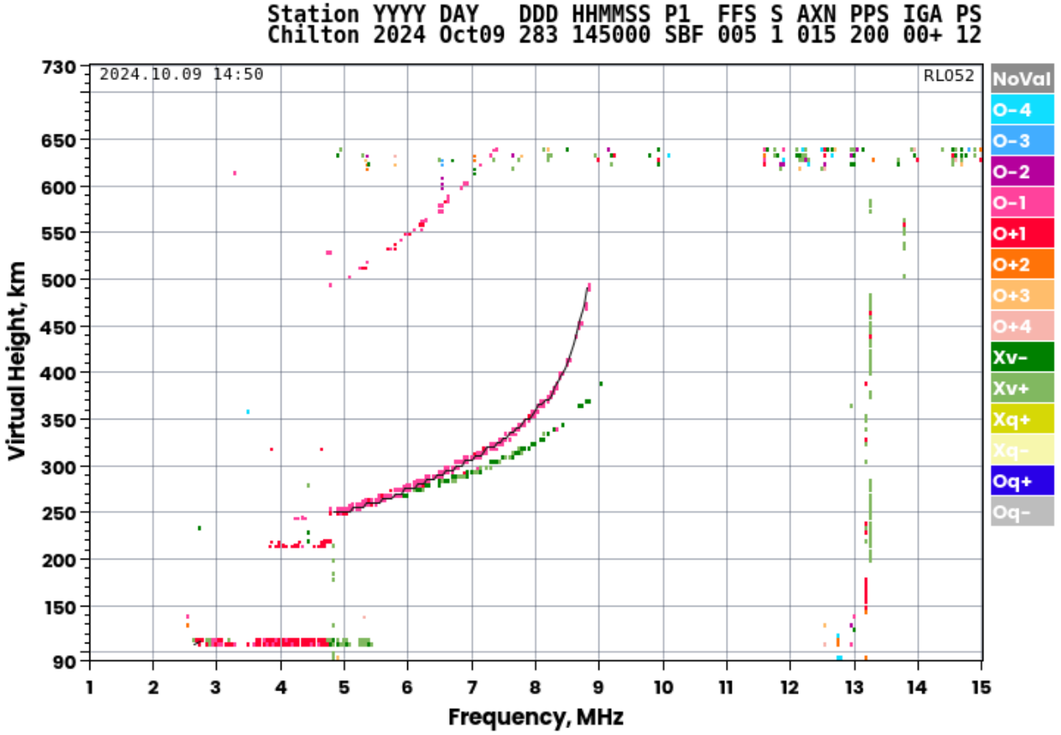


An ionosonde is a swept-frequency radar, beaming vertically upwards

How an ionosonde works

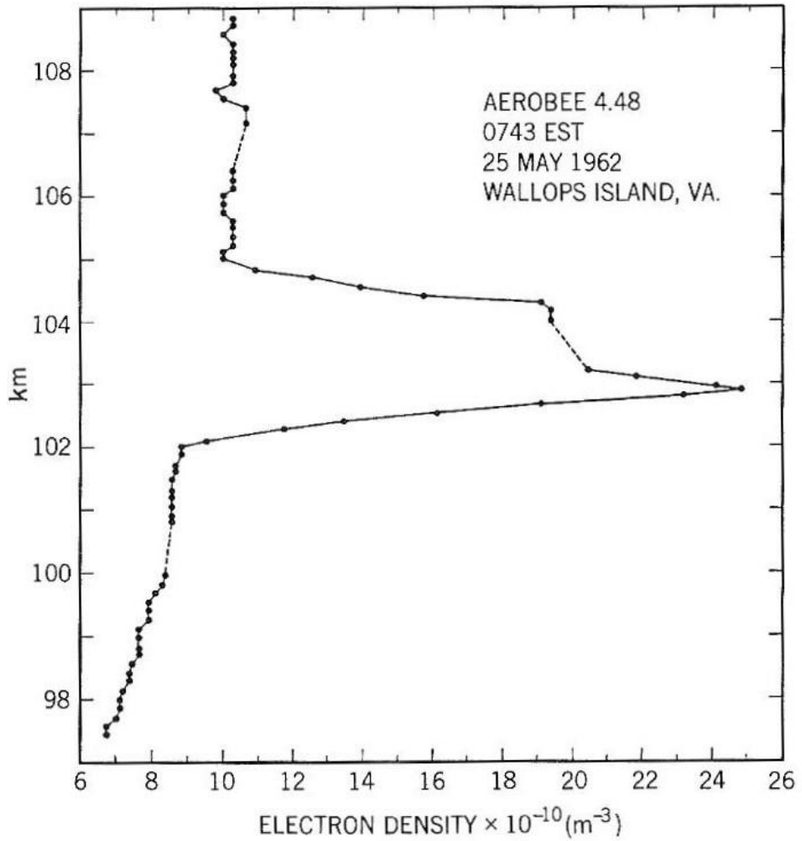


Example real output

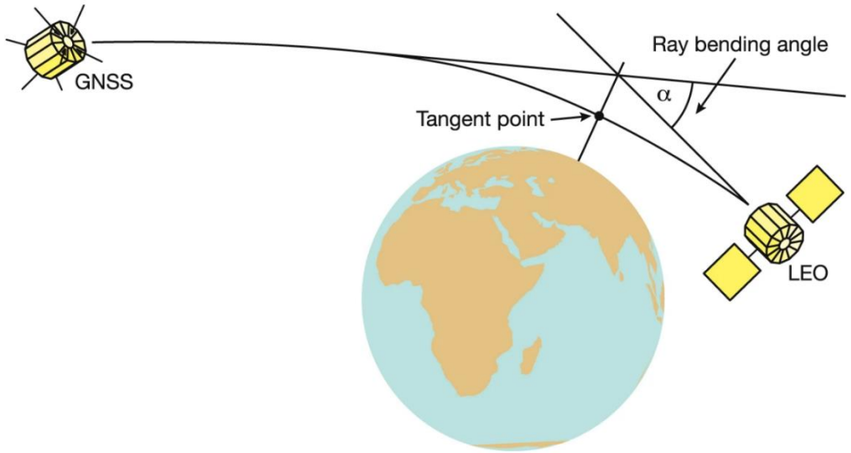


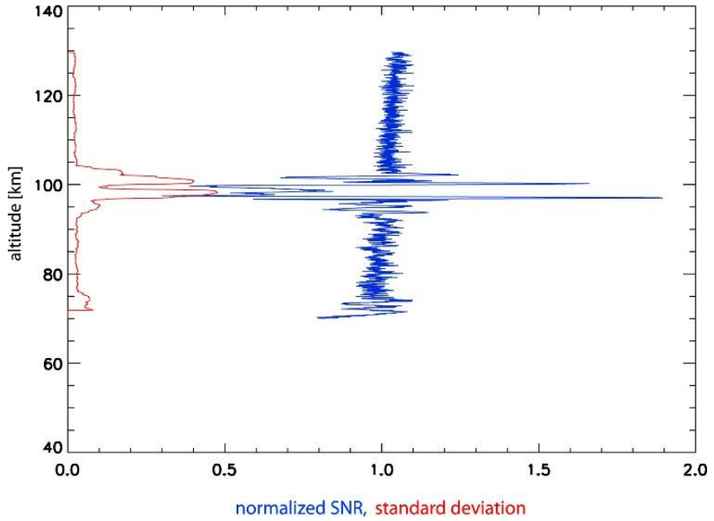
Investigating Es – Rocket studies

- Direct measurement
- Charge probes for electron density
- Mass spectrometers for ion composition (Fe+, Mg+, etc)
- Also ground-based LIDAR for neutral atoms



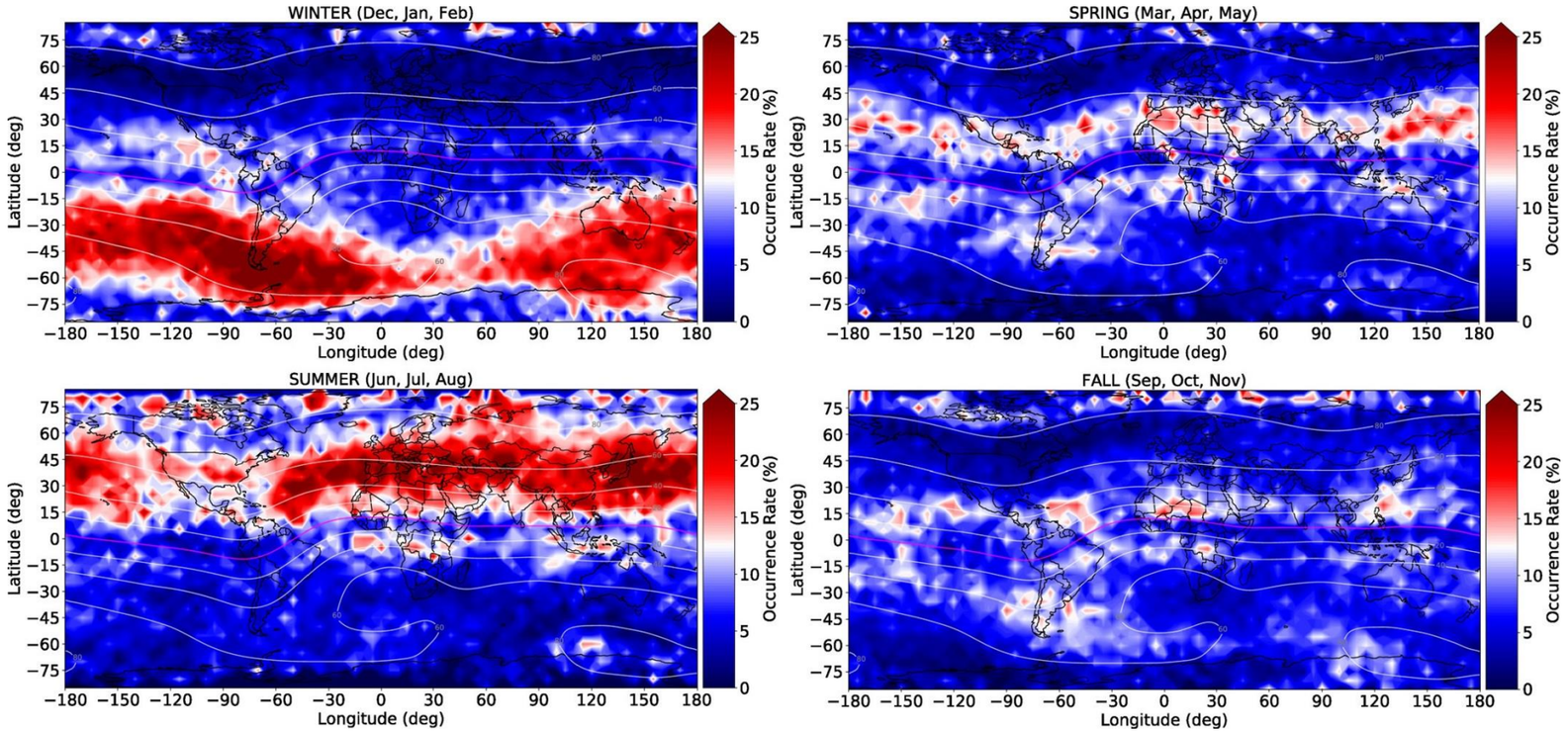
Investigating Es – Satellite Radio Occultation





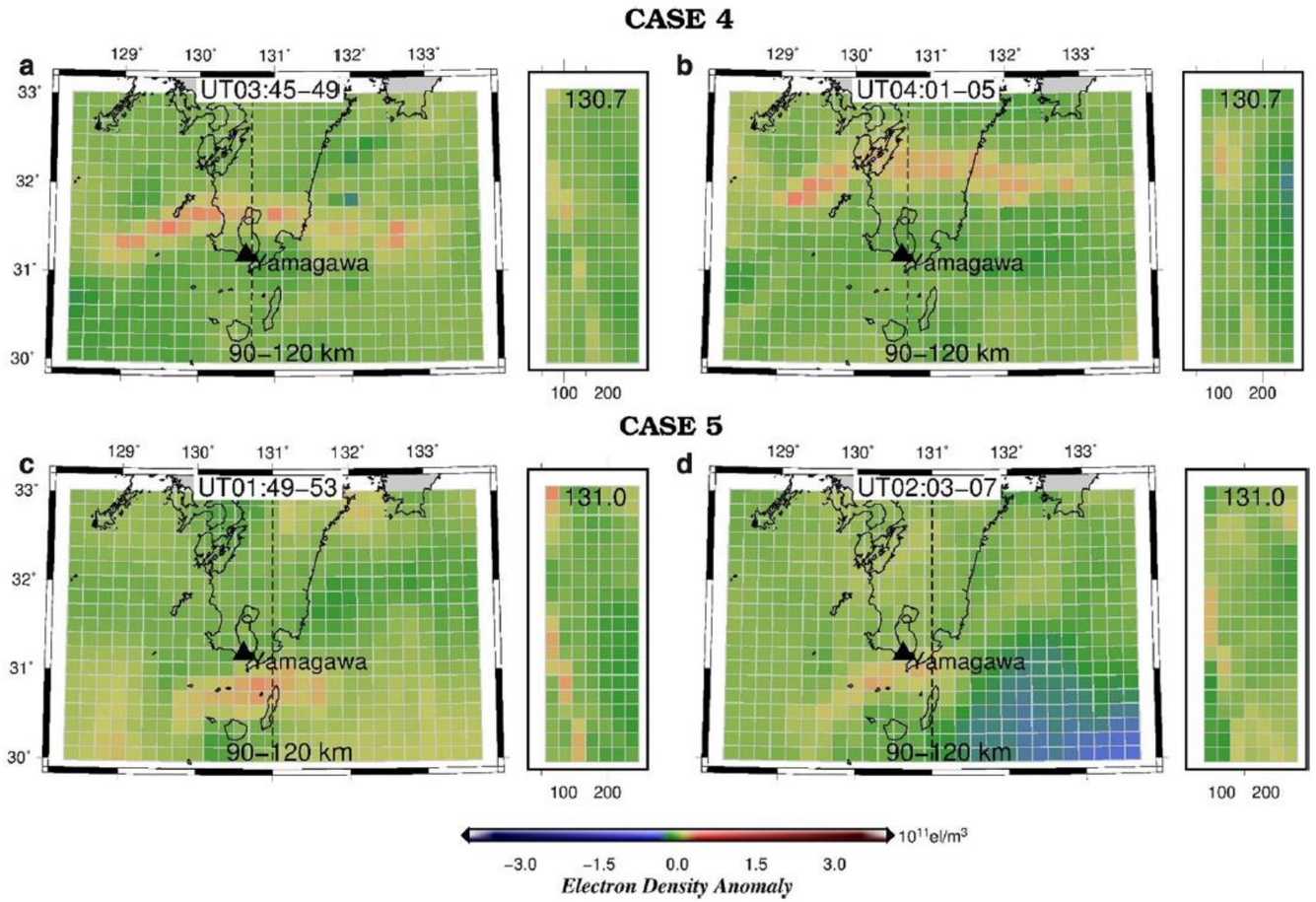
A specialised low-orbit satellite observes the signal from a GNSS satellite ‘rise’ and ‘set’ past the ionosphere

Global frequency of moderate Es

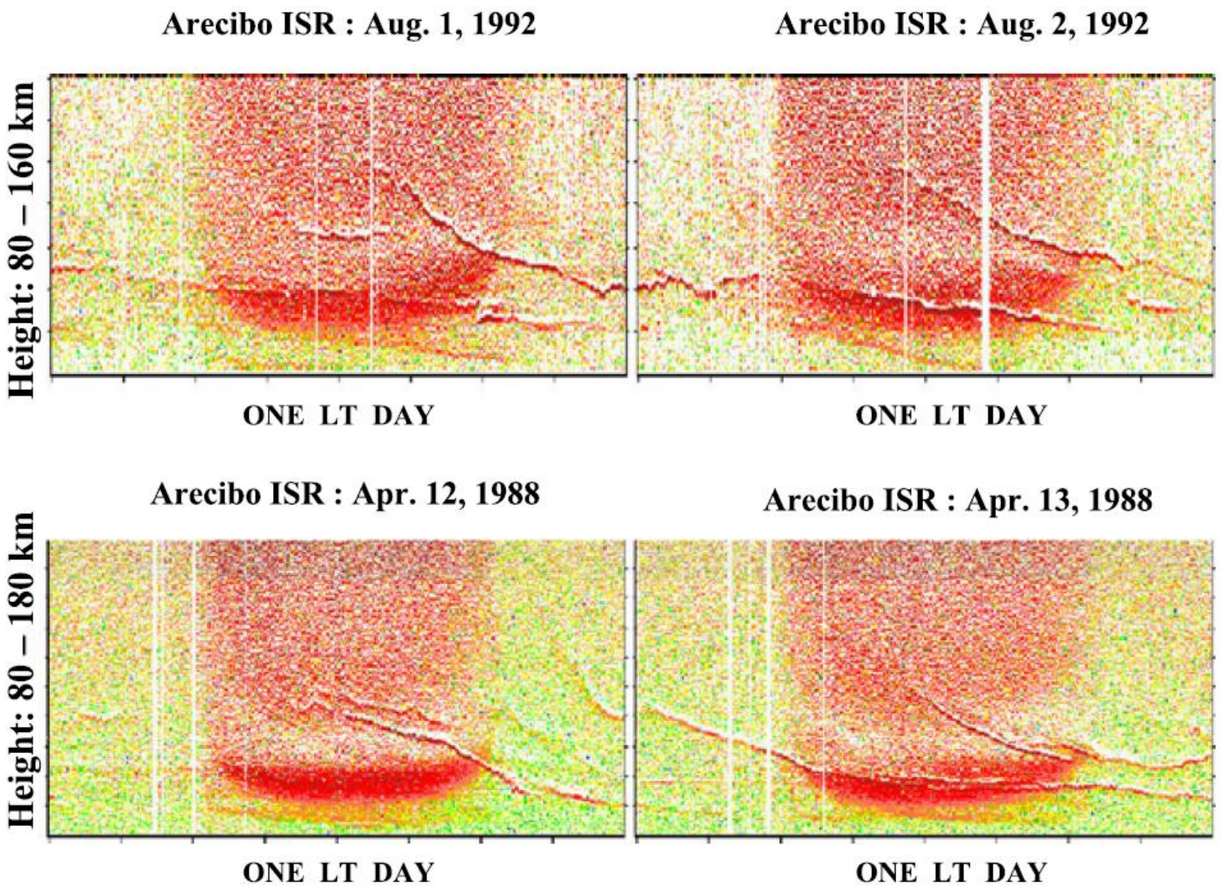


Investigating Es – GNSS Total Electron Content

- Uses signals from global navigation satellite systems, e.g. GPS
- Plotting the size and movement of Es clouds by tracking TEC anomalies
- GPS has two main downlink frequencies, one at 1575.42 MHz (L1), and the other at 1227.60 MHz (L2).
- The ionosphere is dispersive, i.e. the radio propagation speed depends on frequency
- The phase difference between received L1 and L2 gives TEC along the path

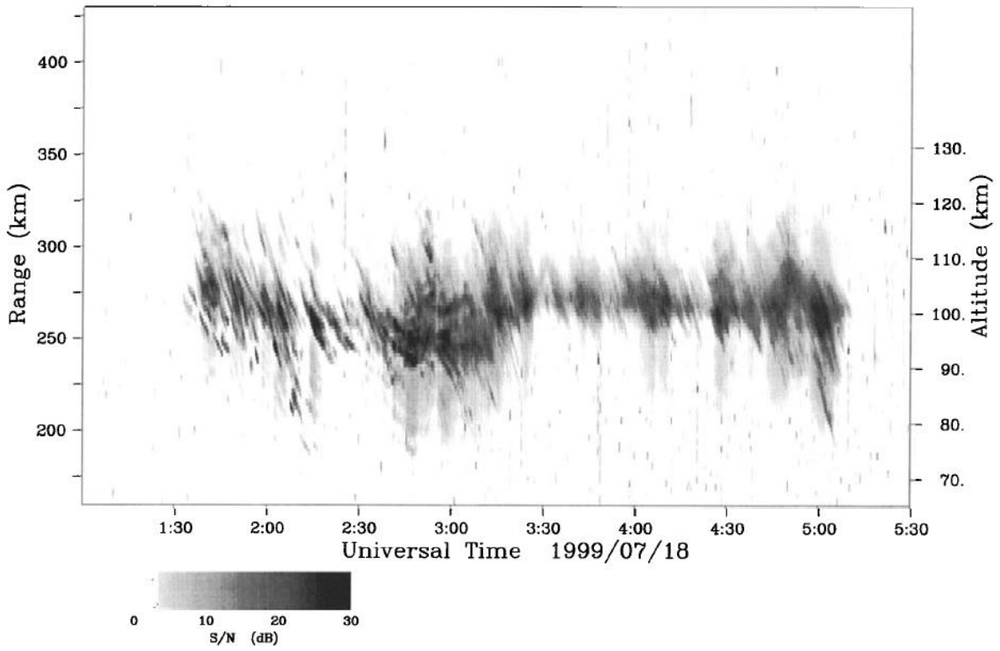


Investigating Es – Scatter radars


Arecibo ISR : Aug. 1, 1992
Arecibo ISR : Aug. 2, 1992
Height: 80 – 160 km
ONE LT DAY
ONE LT DAY
Arecibo ISR : Apr. 12, 1988
Arecibo ISR : Apr. 13, 1988
Height: 80 – 180 km
ONE LT DAY
ONE LT DAY

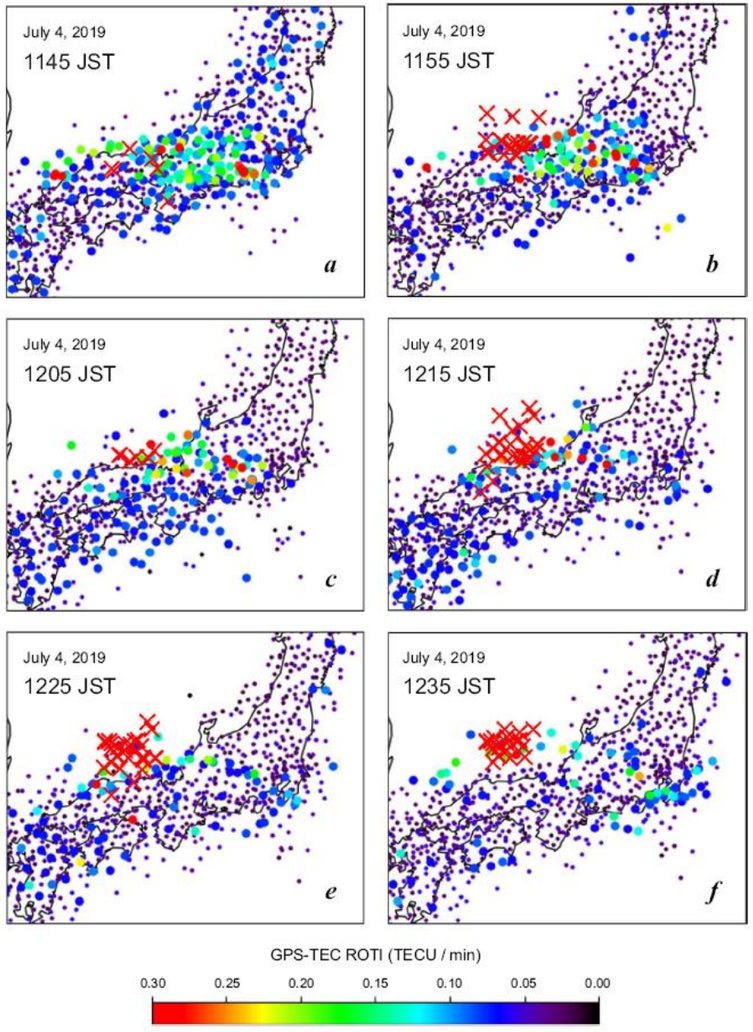
Incoherent Scatter Radar (430 MHz)

Scatter radars show thin, lumpy, bumpy descending layers



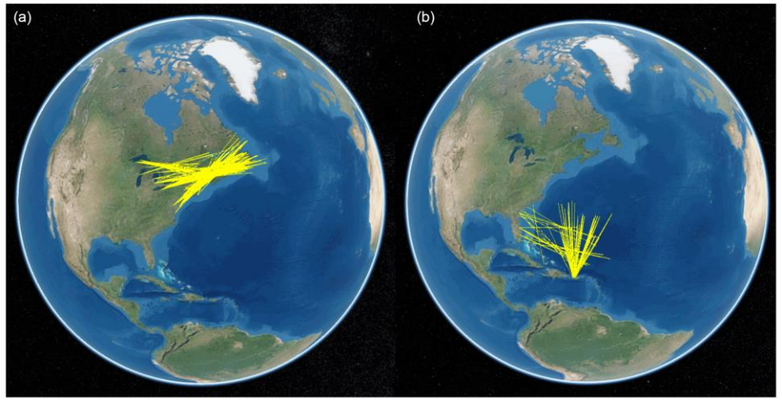
Coherent Scatter Radar (30 MHz)

Investigating Es – bistatic reflection

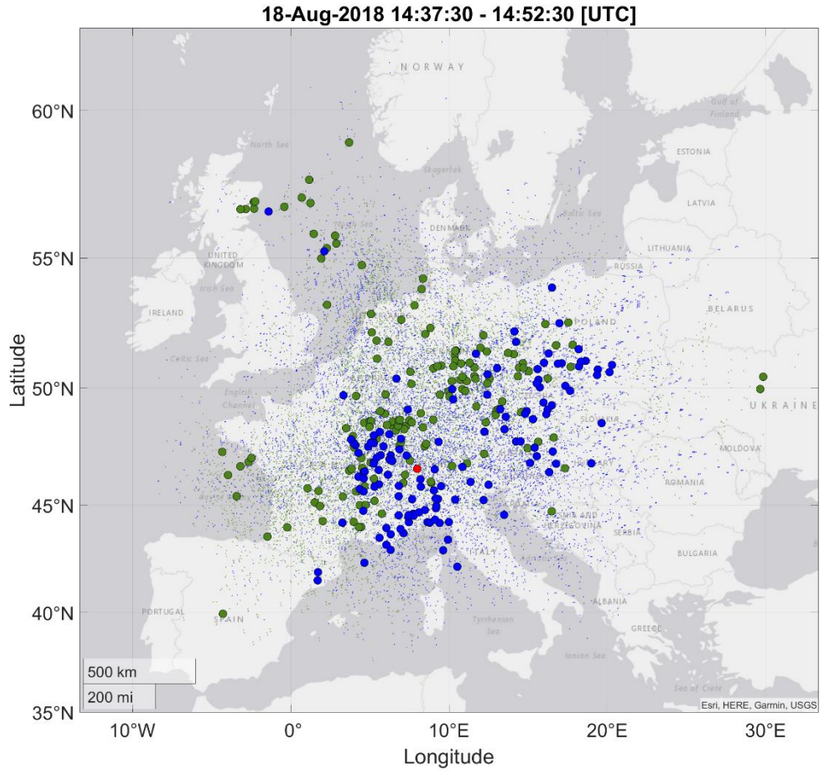


NAV 108 – 118 MHz

Some are dedicated TX/RX experiments, but others use ‘signals of opportunity’ such as amateur, broadcasting, and navigation services

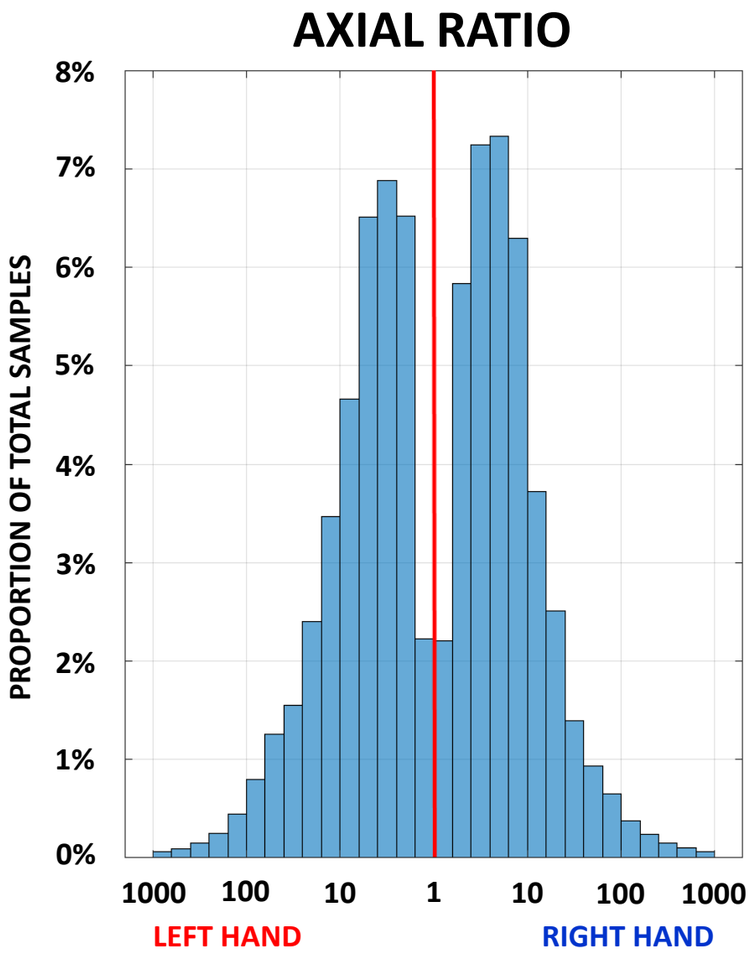


AIS 162 MHz

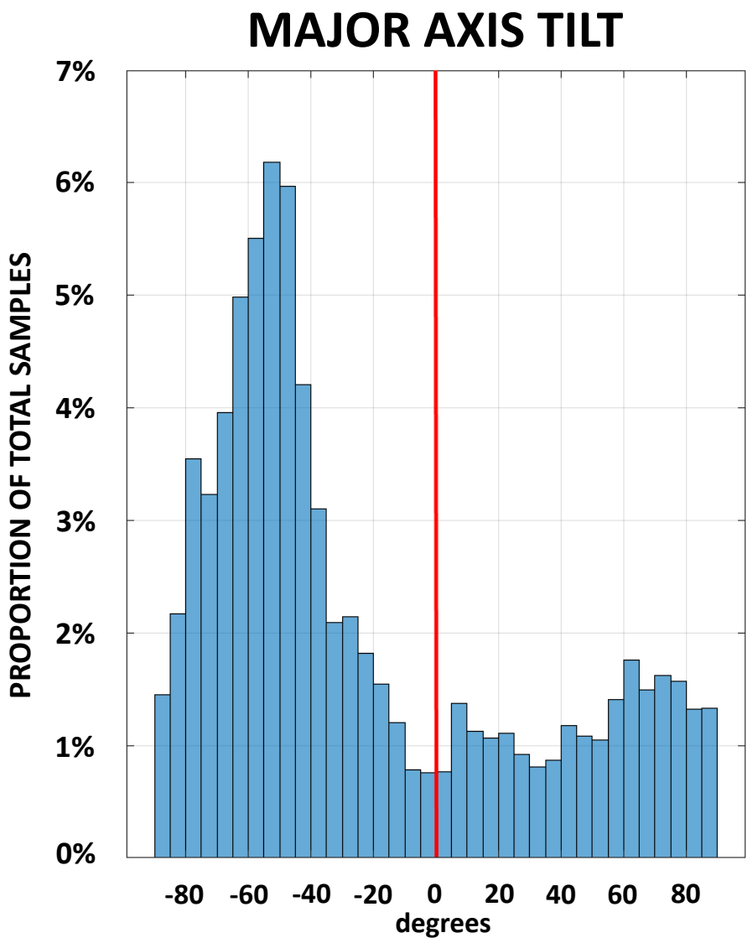


Amateur 28/50/70 MHz

Direct measurement of bistatic signal properties – 50 MHz

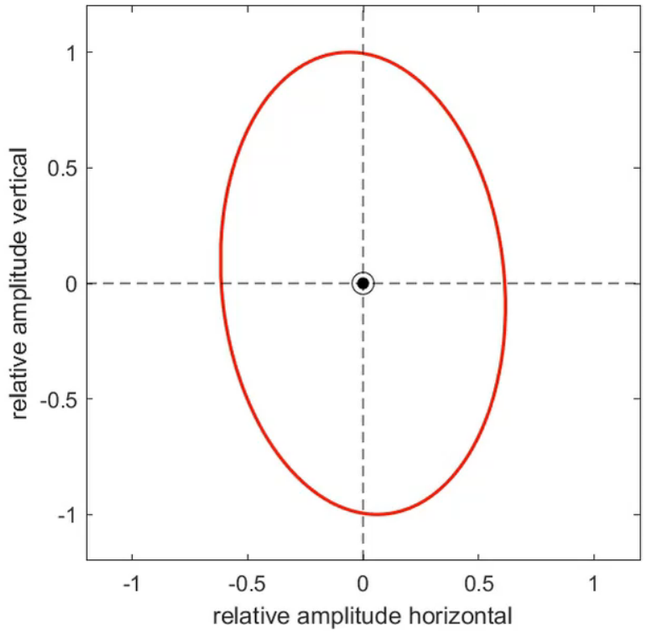


Red centre line => *circular*
Infinite (left or right) => *linear*



Red centre line => 0 deg
(*horizontal)*

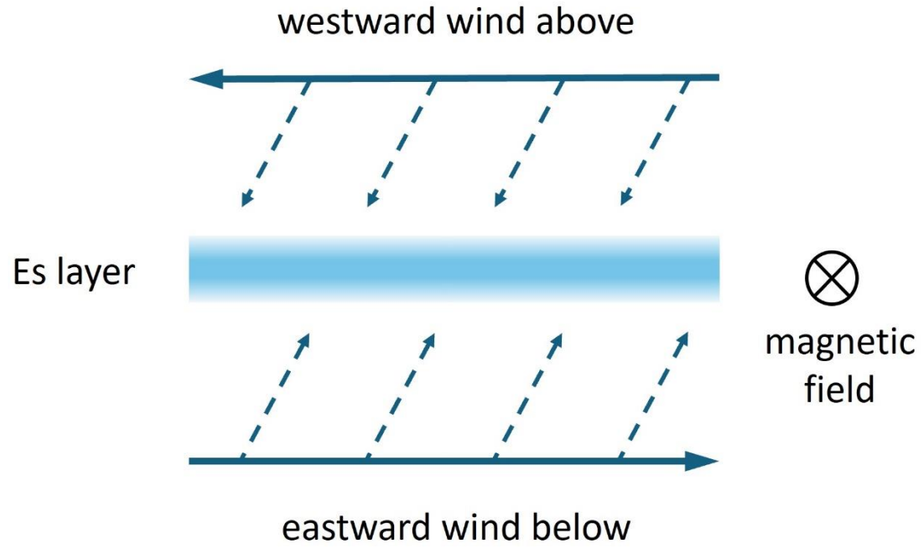
Blue = Right Hand polarisation rotation
Red = Left Hand polarisation rotation

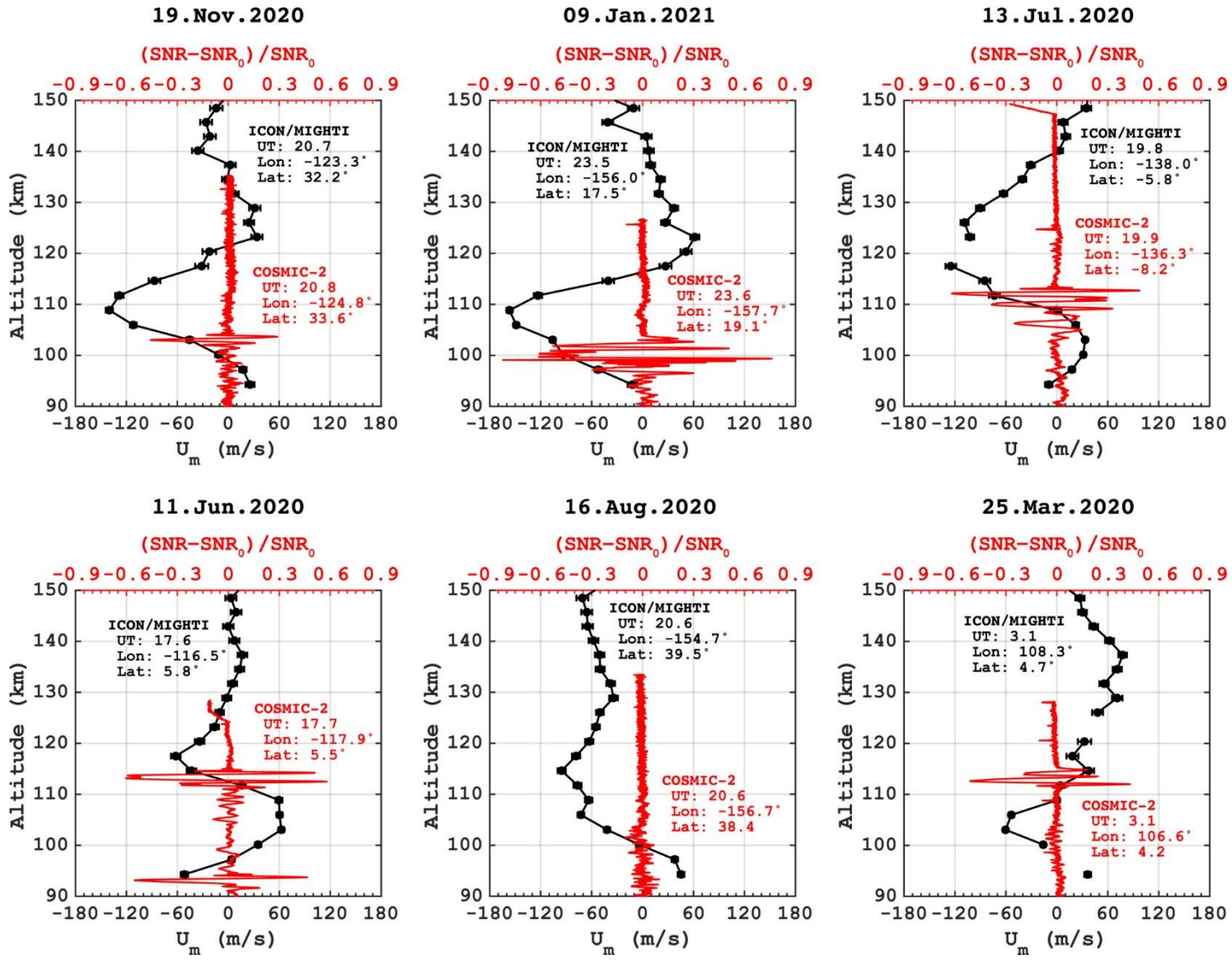


normalised amplitude

The creation of Sporadic-E clouds

Windshear, in the presence of the Earth's magnetic field, concentrates metal ions, and their associated electrons, into thin, dense layers

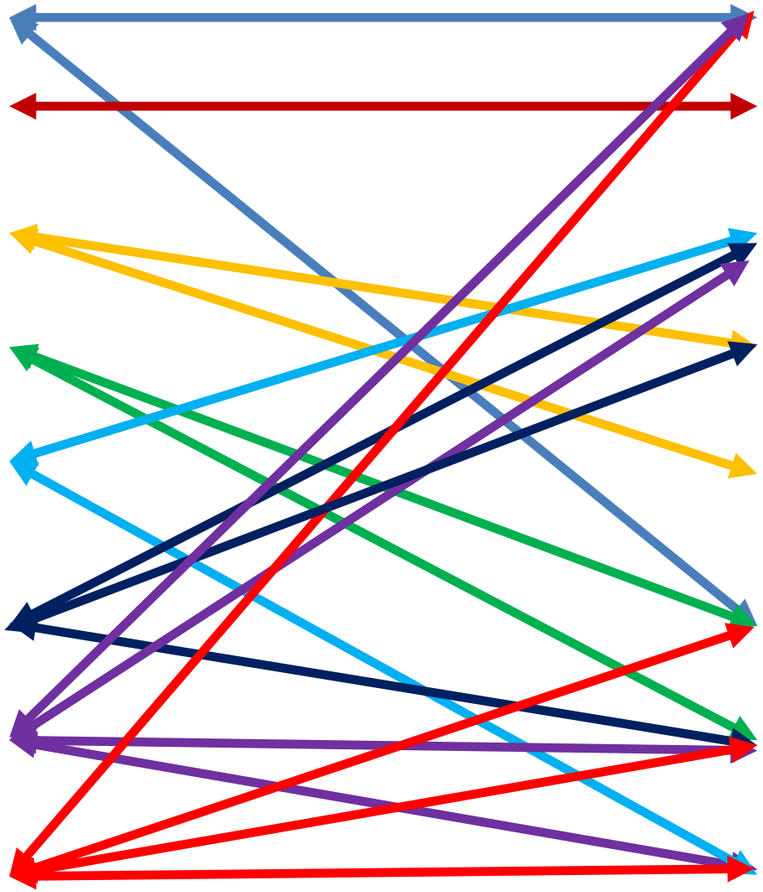




The windshear theory has recently been validated by satellite radio occultation studies

Es physical characteristics cause the weirdness

Es physical characteristics	*Es propagation weirdness*
Very intense ionisation	*HF and VHF, up to beyond 144 MHz*
Occurs in the E Region *(90 - 130 km)*	*Single-hop range to about 2500 km*
Created from meteor debris by windshear linked to solar tides	*Appears from nowhere and can disappear just as quickly*
Thin layers *(0.5 - 5 km thick)*	*Intermittent, very difficult to predict*
Clouds often localised and variable *(a few km to hundreds of km)*	*Independent of the solar cycle*
Moving with upper atmosphere winds *(20 – 130 ms^{-1})*	*Signals can be very strong*
Lumpy and bumpy	*Rapid fading*
Cloud shapes variable, possibly inducing focusing of reflections	*Often very localised*



We need to think of Es as like actual *clouds* in form

Like this…

Or maybe this…

Variable density and thickness

Created by winds

Moved by winds

Turbulence at boundaries

Variable structure

Thinner towards the edges

References

Slide	References
2	• Deacon, C.J., Witvliet, B.A. and Mitchell, C.N. Investigation of the polarisation of 50 MHz signals via Sporadic-E reflection. In Proceedings of the Nordic HF Conf (August 2019). Nordic Shortwave Conference, Fårö, Sweden.
3	• Diagram adapted from Australian Government Bureau of Meteorology, http://www.sws.bom.gov.au/Educational/1/2/5)
5	• Smith, L.G., 1966. Rocket observations of sporadic E and related features of the E region. Radio Science, 1(2), pp.178-186.
6	• Arras, C. and Wickert, J., 2018. Estimation of ionospheric sporadic E intensities from GPS radio occultation measurements, Journal of Atmospheric and Solar-Terrestrial Physics. 171, pp. 60–63. • Hodos, T. J. et al., 2022. Global sporadic-E occurrence rate climatology using GPS radio occultation and ionosonde data. Journal of Geophysical Research: Space Physics, 127, e2022JA030795
7	• Muafiry, I.N. et al., 2018. 3D tomography of midlatitude sporadic-E in Japan from GNSS-TEC data. Earth Planets and Space, 70(45).
8	• Haldoupis, C., 2011b. Midlatitude Sporadic E. A Typical Paradigm of Atmosphere-Ionosphere Coupling. Space Sci Rev 168, 441–461. • Hysell D. L. and Burcham, J. D., 2000. The 30-MHz radar interferometer studies of midlatitude E region irregularities. Journal of Geophysical Research, 105(A6), pp. 12,797-12,812.
9	• Hosokawa, K. et al., 2021. Visualizing sporadic E using aeronautical navigation signals at VHF frequencies. J. Space Weather Space Clim. 2021, 11, 6. • Chartier, A. T. et al., 2022. Long-distance propagation of 162MHz shipping information links associated with sporadic E. Atmos. Meas. Tech., 15, 6387–6393. • Deacon, C., Mitchell, C. and Watson, R., Consolidated Amateur Radio Signal Reports as Indicators of Intense Sporadic-E Layers. Atmosphere, 13(6), 2022, p.906.
10	• Deacon, C., Mitchell, C., Watson, R. and Witvliet, B.A., Evidence for the Magnetoionic Nature of Oblique VHF Reflections from Midlatitude Sporadic-E Layers. Atmosphere, 13(12), 2022, p.2027.
11	• Haldoupis, C., 2011b. Midlatitude Sporadic E. A Typical Paradigm of Atmosphere-Ionosphere Coupling. Space Sci Rev 168, 441–461. • Yamazaki, Y. et al., 2022. Examining the wind shear theory of sporadic E with ICON/MIGHTI winds and COSMIC-2 Radio 2 occultation data. Geophysical Research Letters, 49, e2021GL096202.

Thank you!